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THE NATURE OF VITAL PROCESSES ACCORDING TO RIGNANO.

[CONCLUDED.]

EXPLANATION OF ASSIMILATION.

(Rignano, p. 356): "The fact that strikes us first of all is, that the vital phenomenon depends upon continual reproduction, for assimilation constantly reproduces the substance which is gradually consumed. It is to be expected, therefore, that if there are any fundamental properties of living organic substance which explain the phenomena of development or of reproduction in general, they must then be capable of accounting for assimilation also inasmuch as it is itself also a phenomenon of reproduction.

"That being granted it will be worth while that we next stop for an instant to take a look at and consider briefly a few of the principal conceptions which biologists have put forward on the nature of either the vital phenomenon or of assimilation, and which are of the greatest interest from our point of view.

"Roux, for example, rightly urges that the nature of life must be dynamic. 'Life is in its essence a process, and cannot therefore have a static definition. It is therefore only a processive and consequently functional definition which can approximate the essence of organic life.'[1]

"On the other side we have already seen the reasons for concluding that the essence of the vital phenomenon consists in an activation of nervous energy. We recall that according to Orr for example, the fundamental property of living substance is an 'elemental nervousness.'[2]

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[1] Roux, *Ueber die Bedeutung der Kerntheilungsfiguren.* Leipsic, Engelmann, 1883, p. 18. Gesamm. Abhandl., Bd. II, p. 142.

"We have already seen also that Claude Bernard, in agreement with that, considers the sensibility of the nervous substance as nothing else than a particular modality of irritability, which would be a general property of all living substance. 'Sensibility,' writes he, 'considered as a property of the nervous system, is only a higher degree of a simpler property which exists everywhere in all living substance both animal and vegetable. It has nothing essential or specifically distinct. It is the special irritability of the nerve just as the property of contraction is the special irritability of the muscle and as the property of secretion is the special irritability of the glandular element. These phenomena are so many different degrees of one and the same elementary phenomenon.[3]

"Bard also remarks, that, if the nature of the energy constituting the basis of all vital phenomena must be single, the infinitely varied modalities which these same vital phenomena present must then be due to as many corresponding modalities of this single energy."[4]

Here must be considered the conception which Rignano has himself formed of the general nature of vital energy and which has already been stated in the introduction. He says (p. 361 ff.): "Vital energy, nervous energy, we must admit, will certainly be only a particular case of more general physico-chemical forms of energy already known, or yet to be known, and as such must necessarily be subject to the laws governing the latter, and also *a fortiori* to the laws governing all energy in general. But also as such, i. e., as a particular case of more general physico-chemical forms of energy, it will have in addition special laws of its own, which are only experimentally to be determined, and can not simply be deduced from the more general laws, even though it must always be subjected to them also. And these laws of its own are exactly what make of it, from a simply physico-chemical energy, vital energy. It is just this conception to which we have been led when we have attributed to nervous energy, taken as the fundamental basis of life, special properties, which electric energy, in certain respects related to it, does not on the contrary possess.

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[2] Orr, *A Theory of Development and Heredity.* New York, Macmillan, 1893, p. 86.

[3] Claude Bernard, *Leçons sur les phénomènes de la vie communs aux animaux et aux végétaux*, pp. 289-290.

[4] Bard, "La spécificité cellulaire et ses principales consequences," *La semaine médicale.* Paris, 10. Mars 1894, p. 116.

"If, passing on now to assimilation, we examine the conception which the biologists have made of it, we shall see that their opinions on that subject are quite remarkably concordant.

"Thus, for example, Lewes says: 'The peculiarity of vital processes consists in this; that living matter undergoes molecular changes of composition and decomposition which are simultaneous, and by this simultaneity it preserves its integrity of structure.'[5]

" 'Life,' remarks in his turn Oscar Hertwig, 'manifests itself, expressed in the most general terms, in this, that the cell, by virtue of its own organization and under the influence of the external world undergoes continual changes and develops forces whereby its organic substance, on the one hand continually destroyed with determined manifestations of energy, on the other hand is regenerated.' 'The life process depends then on a continual destruction and re-formation of organic substance.'[6]

"But the clearest and most suggestive of all is Claude

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[5] Lewes, *The Physical Basis of Mind.* London, Kegan Paul, Trench, Trübner & Co., 1893, p. 5.

[6] Oscar Hertwig, *Die Zelle und die Gewebe,* Bd. I, p. 54, and Bd. II, pp. 190-191.

Bernard in the following celebrated passage, 'The characters of life considered in their essence and in their entirety can be classed in two great groups:

" '1. The phenomena of consumption, of vital destruction, which correspond to the functional phenomena of the organism.

" '2. Plastic phenomena or phenomena of vital creation, which correspond to functional repose and to organic regeneration.

" 'Everything which goes on in the living being is in relation to one or other of these types; and life is characterized by the union and combination of these two orders of phenomena.

" 'Disorganization or "dis-assimilation" uses up living material while the organs perform their functions. Assimilative synthesis regenerates the tissue. It reassembles the reserve materials which the functioning organism must use up. These two processes of destruction and renovation, although inverse, are absolutely connected and inseparable, in the sense at least that destruction is the necessary condition of renovation. The phenomena of functional destruction are themselves the precursors and instigators of material renewal of the formative process which completes itself silently in the interior of the tissues.'[7]

" 'But the underlying reason,' says Dastre, 'of this interdependence between chemical destruction and function is made recognizable by energetics. A part of the organic material (reserve material, but also living protoplasm) becomes decomposed, chemically simplified, reduced to a lower degree of complexity, and abandons in this descent the chemical energy which it enclosed within it in the potential state.

" 'Every act which gives out energy, which produces heat, or movement, every manifestation whatever which can be regarded as a transformation of energy, necessarily consumes energy, and this is borrowed from the substances of the organism. The functioning of muscle produces heat and movement, the functioning of glands produces heat, the functioning of nerve and brain produces a small quantity of electricity and heat. All these manifestations of energy rest upon a destruction of organic matter, a chemical simplification as source of the energy manifested. In this way material destruction not only coincides with functional activity but is the measure and the expression of it.

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[7] Claude Bernard, *Leçons sur les phénomènes de la vie communs aux animaux et aux végétaux,* pp. 125-127; 157; 347-348.

" 'The reconstruction of protoplasm is on the contrary a phenomenon of evident synthesis, of a certain chemical increase of complexity, since this living protoplasm stands in a way at the highest stage of complexity. Its formation at the expense of simpler nutritive materials requires then an appreciable quantity of energy.

" 'The phenomena of living beings,' continues Dastre, 'may be divided into two categories. Some are intermittent, alternative and are produced or accentuated at certain times but can not be continuous. These are *functional processes.* There are others in which this property of sudden and intermittent expenditure of energy does not appear at all. They are in general *nutritive processes.* The muscle which contracts, functions. It has an activity and a repose. During this apparent repose one could not say that it was dead. It has life and this is here obscure in comparison with the manifest activity of the functional movement.

" 'The phenomena of functional activity are those which catch the eye and by which we are inclined to characterize life. These are conditional upon processes of consumption, of chemical simplification, of organic destruction through which energy is set free. And it is quite necessary that it should be so since these functional manifestations expend energy. These phenomena in which vital activities are most apparent are the least specific. They have only the character of general phenomena.

" 'The phenomena which accompany functional repose correspond to the reconstruction of the reserve materials destroyed in the preceding period, to organic synthesis. This remains in the words of Claude Bernard, "internal, silent, hidden in the expression of its nature, reassembling silently the materials to be expended. We never see these phenomena of organization directly. Only the histologist, the embryologist tracing the development of the element or of the living being notes the changes, the phases which discover to him this homely work, here a deposition of material, there the formation of a membrane or a nucleus, yonder a cleavage or a folding, or a renovation." This category of phenomena is the only one which has no direct analogues. It is peculiar to the living being and limited to it. This developmental synthesis is the true vital phenomenon. Life is a creation.'[8]

"This new formation of living matter which goes on during the so-called functional rest we must then seek to explain through the properties which we have postulated above for nervous energy taken as the basis of the vital phenomenon.

"For this purpose let us suppose in conformity with the hypothesis set forth above that one could construct an elementary electric accumulator capable of furnishing a single given intensity or specificity of current and that its electro-motive force or difference of potential between the poles is proportional to the mass of substance constituting its charge; as if each new increment however small of this mass constituted an element by itself which would be added in serial order to the others.

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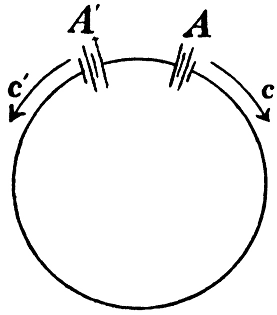
[8] Dastre, *La vie et la mort.* Paris: Flammarion, 1902, pp. 103, 107, 208-209, 210-211.

"Let us consider two of these accumulators, *A* and *A'*, inserted with their poles inverted in the same circuit. Suppose they are quite identical, except that the one, *A'*, is entirely without charge and the other, *A*, has its full charge. Let us suppose that the current, *c*, generated by *A* which tends to charge *A'* can under certain circumstances cause an oscillatory discharge, i. e., a continuous oscillation of the current, now in the direction of *c*, now in the contrary direction of *c'*, and that certain external alternating currents could induce in the oscillating circuit sinusoidal electro-motive forces of the same frequence as this oscillating discharge and thereby strengthen the sinusoidal electro-motive force of the latter which at the beginning was determined by the original difference in charge of the two accumulators *A* and *A'*.



"Then with each half oscillation the one accumulator will become more strongly charged in proportion as the other discharges, and there will be produced as final result a series of oscillations with a consequent continual increase of the total mass of the two accumulators *A* and *A'*, as long as the saline solution serving as their common aliment is not insufficient.

"If the amount of electro-motive force contributed by the induction current at each oscillation is proportional to the amount of electro-motive force which is directly dependent upon the difference in charge between the two accumulators existing at any moment, if for example, it represents a definite fraction of the latter, and thereby will gradually decrease in amount as this difference between the two charges becomes less with each oscillation, then both the amount of this difference and that of the induced electro-motive force will sink to nothing after a certain period of time, theoretically infinitely long, practically more or less short, which we can call the period of reconstitution or of replacement of material consumed.

"As soon as the charges of the two accumulators have become equal there will exist no more provocation of oscillating currents and the total mass of the two accumulators whose increase had become always smaller and smaller will now not increase any further at all.

"But if at this instant either of the two accumulators suddenly becoming inserted aside from its own oscillating circuit at the same time *also* into one of the ordinary circuits, discharges into the latter wholly or partially, then the difference between the respective charges of the two accumulators will again be present and the former process of oscillation will begin again. And this will result again in the increase of the total mass of the two accumulators above the amount which it had already reached before this last discharge. We can compare this discharge of one of the two accumulators outside the circuit of oscillation, with the nervous discharge from the nucleus into its environment, that is, with the biological functional excitation which produces the same trophic effect.

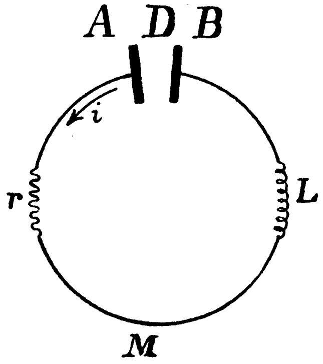
"Further, if at the moment when the two accumulators have arrived at the condition of equality between their respective charges and so of repose, one of them, instead of becoming discharged into another circuit, becomes replaced by a third accumulator whose charge is different from the other two now equalized charges, the result will be the same. And the impulse given to the process of oscillation will be greater, the greater the difference between the charge or electro-motive force of the new accumulator and of the old one replaced. In other words, to make use of biological expressions: the rejuvenescence of the specific potential elements formed by the pair of accumulators will be proportionally greater, the more quantitatively unequal are the two half elements which have become thus mutually fecundated.

"If we substitute for the conception of electro-motive force that of nervo-motive force, our hypothesis concerning the nature of the vital process in each specific potential element or mnemonic element will consist simply in supposing that the latter is comparable to this pair of accumulators inserted with inverted poles in the same elemental oscillating circuit, which we would call intra-nuclear circuit, but in which there enters into play instead of the alternating electric induction current, general thermal energy in the same way.

"Assimilation, the new formation of living substance, would then be dependent, according to this hypothesis, upon a kind of rhythmic oscillatory charging and discharging flux, upon a kind of intra-nuclear oscillatory discharge which becomes induced by the extra-nuclear or functional nervous discharge in consequence of the disturbance of the equilibrium between the nervo-motive forces of the two accumulators opposite each other. The vital element would thus be conceived of as only a double specific elemental accumulator of nervous energy in continual charge and discharge.

"As will be noted we have here a phenomenon in some respects similar to the electric resonators of Hertz, in which an electric discharge caused by the difference of potential existing between the two armatures of a condenser, is transformed into an oscillating discharge. It will be appropriate here to indicate briefly in just what this phenomenon consists.

"Let *A* and *B* be the armatures of a charged condenser which are suddenly connected with each other by an external conductor, *ArMLB,* in such a way that the latter makes a circuit open only at the point *D* of the di-electric. In the accompanying figure *r* represents the total resistance of the circuit and *L* the inductance or coefficient of self-induction of this circuit. When the capacity *c* of the condenser and the inductance *L* of the circuit are in a certain relation to each other, and *r* is *small,* we can get an oscillatory discharge which forms as it were a sinusoidal alternating current: that is, the electricity oscillates from *A* toward *B* and from *B* toward *A,* with a frequency determined by the inductance *L* and the capacity *c.* If we cause the resistance *r* of the circuit to become constantly less by employing wires of constantly increasing thickness, we approach the boundary at which this oscillation will be able of itself to continue indefinitely.



"If in this case where *r* is very small, we excite in the circuit by induction sinusoidal alternating electro-motive forces of the same frequence as in the oscillatory discharge, then there will arise in *A* and *B* differences of very many volts even though the number of volts so induced be very small.

"Upon this principle depends, as is well known, the celebrated experiments of Hertz which in turn have formed the point of departure for wireless telegraphy.

"It is well known also that such an electric resonator has been rightly compared to a vibrating dynamic system, to a pendulum that has an oscillation time of its own, to a sounding chord which the smallest impulses having the same frequence as itself can set in vibration, even in strong vibration. What happens in it is a continual periodic transformation of energy. At the instant when the sinusoidal alternating current reaches its maximum intensity, one has the maximum of actual energy, while the condenser, on the other hand, possesses then no potential energy whatever. At the instant when the intensity of the current drops to nothing, the condenser shows the greatest deformation of the respective di-electric and possesses thus a potential energy fully equal to the actual energy possessed by the discharge at the moment of its greatest intensity, the process being thus exactly the same as in a pendulum in which potential energy is transformed continually into actual and *vice versa.*

"It will be sufficient here, for the purpose of a remote comparison, to note the fact just indicated, that an induced sinusoidal alternating electro-motive force in such an electric resonator, which need amount to only a very few volts, provided that it be of the same frequency as the oscillating discharge, will be able to induce in A and B differences of tension which may amount to many volts. For if we assume in the current so oscillating the faculty of depositing in each of the armatures of the condenser infinitely small particles of substance in series one after the other, until the total of their mass and the consequent electro-motive force surpass the electro-motive force in the opposite direction, which this current possesses at this point and at this moment, then it will not be difficult for us to understand the case in certain respects analogous, which we have assumed for the oscillating nervous discharges, in which the calorific oscillations which replace here the oscillations of the induction current continually increase the mass of living substance, which will in this way be 'assimilated.'

"Let us note that in the case of nervous currents we must assume that their specificity is constant even during the oscillation. At the same time, however, the duration of each nervous discharge, and hence of each oscillation also, in cases where the specificity i of the nervous current is something dynamically equivalent to the intensity of the electric current, must be definite and constant for every given specificity.

"For let us consider again an electric current. If its intensity i persists for a time t, the total actual energy furnished during the whole of this time by this current will be Eit, where E represents the electro-motive force. But this total energy will necessarily be proportional to the mass M of the substance whose decomposition during the time t has produced this current; one has thus $Eit = hm$, where h is a coefficient of proportionality, dependent solely upon the units of measure selected. But if the supposition which we have accepted for nervous currents in general holds good also for this electric current, namely, that the electro-motive force is proportional also to the mass of substance which tends by decomposition to produce the current, then also is $E = km$, where k again is a coefficient of proportionality dependent likewise solely upon the units of measure which are adopted. Consequently the above equation would take on the following form:

$$km.it = hm, \text{ that is,}$$
$$it = h/k = H,$$

where H again is another coefficient of proportionality and dependent alone upon the units of measure already fixed above, that is, upon a selected, constant number. It follows from this, that *it* is constant. And if *i* in its turn is likewise constant for each specific current, *t* must also be constant; i. e., each definite specificity of current, *i* will correspond to a likewise determinate and constant period of discharge.

"If then, no matter what conditions the different discharges of a current of the specificity *i* may induce, all these discharges can have invariably only the same duration *t* and if this holds also for those which constitute the oscillating discharge, then the oscillation itself, which consists of a doubled discharge, of which each one has a direction contrary to that of the other as we stated above, will have necessarily a very definite and constant period of its own which corresponds each time to the particular specificity *i* of its respective current.

"It follows that of all the vibrations of the different calorific rays, only those which have the same oscillatory period as the element being reconstituted will be able to some extent to give to the oscillating discharge of the latter an impulse which will be added to that received through the difference in potential of the pair of accumulators, and thus to have identically the same effect as that which the sinusoidal electric alternating induction current has upon the electric accumulator with an equal period of vibration. And this becomes so much the more clear since Maxwell's theory, of which it is scarcely necessary to remind any one, and which was wholly confirmed by the Hertzian experiments, has demonstrated the essential identity of these electric induction oscillations across the di-electric formed by the air, with light and heat vibrations in general. The only difference consists in the period of vibration which in both the latter is much more rapid than in the former.

"Thermal energy then, whether that which comes from the irradiation of the sun and from the outer world in general, or that which is developed from chemical processes of decomposition and oxidation taking place in the interior of the organism, would, in as far as it is composed of heat rays of the most different periods of oscillation, constitute the general external stimulus which actuates indifferently all vital processes whatever. Particular kinds of energy, which oscillatory periods varying within narrow limits and possibly even with a single vibratory period, such as the rays of each of the elemental colors of the solar spectrum would constitute on the other hand, special external stimuli which activate only the vital energies of this or that corresponding specificity.

EXPLANATION OF NUCLEAR SOMATIZATION.

"Therefore if we suppose a cell to exist whose nucleus contains at the same time various specific elements, each having a specific vibration period of its own, and if we assume that this cell is thenceforth always exposed to the same external stimulus with a constant vibration period, then among all the mnemonic elements, that one which is syntonic with this external stimulus will increase in mass since it absorbs always larger quantities of the nutritive fluid, and at the expense of all the other elements, so that in this way it may result that it supplant them all and remain the sole survivor. We may express this process by saying that the cell has undergone a complete nuclear somatization.

"Let us assume inversely that a cell whose nucleus contains one or several mnemonic elements is exposed at the same time as to the other stimuli, also to a new external stimulus, whose vibration period may differ from all those of the mnemonic elements already present. Then we can assume that this new vibration period may communicate its own frequency to one of the oscillating discharges already present and probably not to the whole nervous current constituting one of these discharges, but to only a part of it, i. e., it will make it syntonic with itself. The result will be the gradual deposition of a new specific substance or mnemonic element which, if this new external stimulus does not permanently displace all the others but co-exists or alternates with them, will merely add itself to the preexisting. We may express this process by saying that the cell has experienced the influence of the new stimulus to which it has been exposed, or that it has experienced the 'imprint' of the new condition through which it has passed.

"It is the same thing if we say that instead of being exposed to a new external stimulus, having a rhythm different from all the preceding, the nucleus is constrained, in consequence of any given new functional adaptation on the part of itself or of its immediate environment, to divide some one of its specific currents into two or more components, or indeed, to receive some new specific current derived from the combination of other specific currents of the environment.

"In the circumstance that at each alteration of any period of oscillation or of any specificity of current through the action of a new stimulus, external or internal, there follows immediately the deposition of a new substance which adds itself to all the others already present and remaining unaltered, and which is capable of exciting only such currents as are syntonic or specifically identical with that by which it was itself deposited; in this circumstance the first and fundamental mnemonic process underlying all living substance would consist. From it would then spring directly all the other processes, from histologic differentiation and the inheritance of acquired characters up to mnemonic phenomena proper.

"Let us note that for each specific discharge, for the intra-nuclear oscillating as well as for the extra-nuclear functional, there will correspond very definite substances of dissimilation, for the different specificities of the nervous currents can be due only to the decomposition of substances similarly different. And even if the diversity of these extremely complex and unstable substances consists only in the different number and different mode of grouping of the same atoms of the principal elements which constitute all organic substance, nevertheless the respective substances of dissimilation to which each of these complex substances will give rise, will necessarily be different from one another. These substances of dissimilation, definite and peculiar for each specific discharge, will in their turn afford, by their entire or partial oxidation, products of excretion and secretion quite definite and differing from one cell to another. These products, in their turn, thanks to their peculiar physico-chemical properties, will impress upon the protoplasm or cytoplasm a corresponding physico-chemical character. And as at the same time the deposition and the arrangement of these materials in the body of the cell is a consequence, in part of the physico-chemical properties inherent in them, in part of the paths, which the respective extra-nuclear nervous discharges or currents will have followed in the cytoplasm according to their specificity, so it is conceivable how the *ensemble* of the mnemonic elements constituting a given nucleus can determine its own protoplasm or cytoplasm both from the purely physico-chemical and from the properly morphological point of view.

"We arrive thus at a constant double correlation between the cytoplasm, the species of nuclear excitation and the substance of the nucleus. The nuclear substance, in fact will determine at once the rhythm of charge and discharge, and the specificity of the corresponding nervous current; and this specificity of current, thanks to the substances of dissimilation to which it will give rise, will determine the respective cytoplasm. Conversely, the rhythm, once it is modified by the functional stimulus, will immediately induce the corresponding modification of the specificity of current; and the latter in its turn will at once determine the substance of synthetization or nuclear substance, as also the substances of dissimilation of which the cytoplasm is constituted.

"It is not excluded either that chemical substances which may act upon the cytoplasm and modify it chemically can facilitate the formation of such or such substances of dissimilation and thus facilitate the production of such or such new specificities of currents which in their turn will deposit or determine the respective nuclear substance. In other words, we do not exclude that besides the physical functional stimuli which preferably influence the vital rhythm directly, there may also exist chemical functional stimuli, which act directly, rather upon the nervous specificity. But thanks to the close correlation between the specificity and the rhythm of these currents, both come to the same result, namely that each contributes its respective mnemonic element to the nuclear substance."

(Pp. 319-320): "Let us note, parenthetically, that nuclear somatization conceded, we must regard each of the substances which make up the different specific potential elements of any nucleus as capable of gradually replacing the others by continual increase of its mass, when the respective specific current, on account of the incessant repetition always of only one and the same stimulus passes very frequently through the nucleus. A nucleus thus somatized,—that is to say, one composed wholly of a single specific substance and which would acquire in this way, on account of the considerable mass of this substance a potential energy capable of overcoming a considerable resistance to its discharge, will then be able to respond to stimulus always in that single way only which corresponds to the single specific nervous current which it is able to activate and which constitutes its irritability, even if it be provoked to discharge by external influences or accidental stimuli which are quite different from those to which it is ordinarily exposed. 'A muscle cell,' says Oscar Hertwig, 'replies to every kind of stimulus by contraction, a gland cell by secretion; an optic nerve can perceive only light, no matter whether it be stimulated by light waves, by electricity or by pressure. Similarly plant cells also are endowed with their own specific energies: the reaction to stimulation receives everywhere its specific stamp from the particular structure of the irritable substance, or in other words, irritability is a fundamental property of living protoplasm, but under the action of the environment manifests itself in specific reactions according to the structure of that protoplasm.' "[9]

Resuming again (pp. 377 ff.): "Let us summarize what has been said. The specific potential elements which have presented themselves above as specific elementary accumulators, and as mnemonic elements, appear now as specific vital elements, that is, as the smallest possible particles of organic substance capable of life. At the same time the denominations *potential* element and *vital* element, which might at first have appeared incompatible with each other, if the adjective *potential* had indicated a vital nonactivity at that time, become entirely compatible in consequence of the hypothesis which we have just set forth. According to this hypothesis, the element would be potential in so far as each of the two coupled accumulators would be able to furnish at need its proper extra-nuclear functional nervous discharge; and it would at the same time he conceived as in a *vital* process by reason of the intra-nuclear oscillating discharge, which continues incessantly between the two accumulators. Vital energy could thus present itself in three distinct modes: (1) In the potential, properly so called, which expresses itself in the phenomena of effective suspension of life or lethargy in its widest sense; (2) In the oscillatory potential, or the intra-nuclear oscillating discharge, which constitutes the essence of the period of so-called 'functional repose,' 'organic reconstitution,' 'storage of materials afterwards to be consumed,' 'assimilative synthesis,' or 'vital creation'; (3) Finally in the actual proper, or the extra-nuclear non-oscillating discharge, which constitutes the period of 'excitation,' 'functional activity,' 'wear and tear,' 'consumption of material stored up in the rest period,' 'disassimilation,' or 'vital destruction.'

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[9] Oscar Hertwig, *Die Zelle und die Gewebe,* I, p. 76.

"In this way, the fact upon which Dastre rightly insists, that 'after the explosive destruction of a chemical reserve,' constituting the functional activity, the living substance still always preserves in the state of repose which succeeds the same properties though attenuated, which it manifested in the state of activity, would find an immediate explanation. Hence the period of repose cannot be of another nature than that of the state of activity as Claude Bernard was inclined to think. 'To-day,' writes Dastre, 'if we had to express a more personal opinion upon this important distinction of functional activity and functional repose, we should say that, after having distinguished the two categories of phenomena it is necessary to try to bring them together. It is necessary, for example, to seek what there is in common between the muscle in repose, and the muscle in contraction, and to perceive in the muscular tonus a sort of bridge thrown between the two conditions. The function would experience no interruption, but it would have its degrees. The muscular tonus would be the permanent condition of an activity which is merely susceptible of being considerably heightened or weakened.'[10]

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[10] Dastre, *La vie et la mort,* p. 212.

"As conclusion of our exposition let us note very briefly that for three more of the most fundamental phenomena associated with vital activity this hypothesis upon the nature of life presents at least the beginning of an explanation. These are: rhythmicity, a characteristic property of all life phenomena; the phenomena of fecundation and rejuvenescence in general; and nuclear division with all its characteristic and remarkable details.

EXPLANATION OF RHYTHMICITY OR PERIODICITY.

"A whole series of facts forces us to the opinion, that rhythmicity should be reckoned among the most general characteristics of the modes of manifestation of vital energy. Beyond the fact that nearly all, and perhaps all external physical stimuli, from the thermal and luminous to the acoustic are characterized by vibrations; and beyond the other fact, a consequence of the first, of the physiological action exercised by musical rhythms and intervals for example, and by all the rhythmical manifestations of the most diverse energies, we see that a more or less manifest and more or less regular periodicity is a fundamental character of all or nearly all biological functions. One thinks at once for example of the synchronous rhythm of all the peristomal cilia of an infusorian—a rhythm which manifests itself in the two parts of an animal which has been divided, provided these parts remain connected by a bridge of protoplasm; of the rhythmicity present in the protozoa in general, present even within the cells in the pulsation of contractile vacuoles, which empty and refill themselves continually at regular intervals; of the beat of the heart, even independent of its connection with the nervous system; of the similar pulsations of the whole vascular system, the entire breathing apparatus, the uterus, and of many other organs; and finally of the periodicity of a whole series of physiological variations, which animals and plants undergo as a result of corresponding periodical variations of the outer world, but which persist unaltered for some time even when the outer world or the periodicity of its variations may have changed.

"Now it is not difficult to conceive of this rhythmicity or periodicity which nearly all biological functions present, as a consequence more or less direct or indirect of the vital phenomenon in all its generality, when this phenomenon, be it only in so far as a phenomenon of assimilation, is itself essentially a rhythmic phenomenon.

EXPLANATION OF FECUNDATION.

"In regard to fecundation we know that it was Spencer who first recognized what has been more or less explicitly accepted by others, that it consisted probably in a perturbation of an equilibrium which tended toward a stability unfavorable to vital activity.[11]

"Now we have already seen how our hypothesis set forth above is able to make at once conceivable in what this equilibrium unfavorable to vital activity may consist. According to this hypothesis, it would consist in the equalization toward which the masses, and the corresponding potentials, of the coupled accumulators of each mnemonic element would tend and which they would eventually attain, and this equilibrium would be disturbed by the substitution for one of these accumulators of another specifically equal to it but differing in mass and potential. And it is precisely in this function of fecundation, of replacing in each couple one of the specific accumulators by another differing quantitatively as widely as possible that we find an explanation of the fact that the rejuvenation of the germ and the consequent vitality of the progeny to which fecundation tends, are proportionally greater when fecundation occurs not between individuals too closely alike, but rather between individuals who belong indeed to the same species but are somewhat dissimilar.

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[11] Spencer, *Principles of Biology,* I. pp. 340-341; II, pp. 614-616.

"According to the same hypothesis, this equilibrium could also be deranged by the extra-nuclear discharge of one of the two coupled accumulators, and this is just what is demonstrated by the universally known experiments upon the rejuvenescence of the infusoria, by which it appears that this rejuvenescence can be reacquired even without any need of the ordinary fecundating conjugation, simply by causing some change in the surrounding conditions of life, and thereby provoking a strong renewal of the functional activity.[12]

"Let us note parenthetically that if oscillating discharges take place between the corresponding separated specific accumulators or half mnemonic elements of the egg and spermatozoon respectively even when the egg and spermatozoon are still relatively distant from each other, i. e., before they could coalesce into a single fecundated nucleus, we can then understand how the space between each pair of these elements can and must function just as the deformed dielectric between the two armatures of the condenser of the electric resonator, and thus be constrained to produce the attraction of each spermatic half element to the corresponding half element of the ovum. And this would have as a final result an energetic reciprocal attraction between the ovum and the spermatozoon.

"The real cause of the sexual attraction of the two germs, male and female, would then reside in their capacity of *vibrating in unison.* Conversely, the absence of all attraction between ovum and spermatozoon belonging to animal or vegetable species distantly related would be due to the fact that they would represent potential half elements, of which there would be too great a number, for example in the spermatozoon, completely different specifically from those of the egg, and they could not possibly, therefore, have the same rhythmicity.

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[12] Hartog, "Problems of Reproduction, etc." *Contemporary Review,* July, 1892, esp. pp. 94-95, 100-102.

EXPLANATION OF KARYOKINETIC CELL DIVISION.

"As to indirect or karyokinetic cell division, let us note that, when each of the two coupled accumulators, in consequence of the continual increase of its mass attains too high a potential, the two halves of each of these accumulators will tend to repel each other, just as would, for example, the two halves of a conducting sphere or disc, charged with too great a quantity of static electricity of the same sign.

"If we admit at the same time, that the separation of the two halves of each accumulator would break abruptly the circuit of oscillation, as would seem indicated by the rupture, retraction, and disappearance of the meshes of the nuclear reticulum during mitosis, and thus suspend temporarily the oscillating discharge, then the nervous energy of this discharge being still at that instant in a dynamic state along the same circuit of oscillation will remain no longer actual energy, but on the contrary becomes transformed into potential, and discharge itself upon the first little bit of substance most capable of receiving it. And this substance, likewise, when once charged with static nervous energy of the same sign must divide also into two parts and thus must form two distinct centers of attraction which mutually repel each other. Consequently, without pretending thus to be able to penetrate into the smallest details of this phenomenon, we understand nevertheless how vital phenomena of *dynamic* order, which are due to the oscillating nervous discharge, must then necessarily be followed by phenomena of *static* order, quite similar to the corresponding phenomenon which the oscillating discharge of an electric resonator would offer, if its oscillation being suddenly interrupted it discharged itself straightway upon any heap of conductive metallic filings which it encountered, transforming itself from dynamic to static electricity.

"This view would find support especially:

"1. In Delage's observation that in indirect division the longitudinal splitting of the chromosomes or of the nuclear filament begins before achromatic filaments are present which are capable of exerting upon them any pull whatever, from which it may be inferred that it is repulsion which operates between the two halves;[13]

"2. In Hansemann's observation, that during karyokinesis all the peculiarly vital functions of the cell, as assimilation, secretion, etc., are completely suspended;[14]

"3. In Watase's observation, according to which the centrosome in reality is only a simple cytomicrosome but of greater circumference and greater force of attraction, and that the cytomicrosomes which always lie at the meeting point of three or more cytoplasmic fibres, likewise are nothing else than small clumps once quite aspecific which form anew in each cell division and from which arises the contractile substance of the cytoplasmic fibres themselves;[15]

"4. In Ziegler's experiment, in which the poles of the horse-shoe magnet took the place of centrosomes and acted upon iron dust strewn upon a thin horizontal wax plate upon which previously pieces of iron wire of forms similar to that of the chromosomes had been placed, and in which figures were obtained which were quite similar to those presented in nuclear division, which is a direct proof of the conception already advanced by Roux, that in the attraction exerted by the centrosomes upon the chromosomes there are in play static energies of nature similar to that of magnetic force or of static electricity."[16]

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[13] Delage, *De l'hérédité* etc., pp. 149-150.

[14] Hansemann, *Studien über die Spezifizität, den Altruismus und die Anaplasie der Zellen,* p. 10.

[15] Watase, *On the Nature of Cell-organization,* Boston, Ginn, 1894, pp. 92-93; and *Origin of Centrosomes,* Ginn, 1896, pp. 282, 285.

The hypothesis which Rignano suggests seems, then, to show how very many of the characteristic phenomena of living beings may be scientifically explained. It is a simple hypothesis, based directly upon properties of physical energy which are well understood. The additional specific properties which it attributes to vital energy, seem to be quite in accord with the properties of physical energy so far as they are known, and to be such as they might, under certain conditions, be expected to present, seem also to be very directly indicated by certain biological processes, especially by memory and ontogeny.

The great reason why it must be very seriously considered, lies in the fact that it explains so much which heretofore has seemed beyond the reach of explanation or even of speculation. Assimilation, rhythmicity and periodicity, mitotic division of cells, fecundation, memory, ontogeny with its orderly repetition of ancestral forms, heredity—these phenomena, the most fundamental and constant of all those manifested by living things, have been just those most difficult to explain. Biological details have been thoroughly worked over. The vast store of observations upon them, and upon the modes of action of the fundamental vital processes, constitute the science of biology to-day, but upon the essential nature of the productive cause of all the varied phenomena of life, biology is relatively silent. The problem has been so difficult that by many it has been hopelessly abandoned, though surely hints of the solution must come up before us constantly in our daily work, if we could but understand them.

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[16] Ziegler, "Untersuchungen über die Zellteilung," *Verhandl. der deutschen zoologischen Gesellschaft,* Leipsic, 1895, pp. 78-83. Roux, *Ueber die Bedeutung der Kernteilungsfiguren,* Leipsic, Engelmann, 1883, p. 18.—Marcus Hartog, "The Dual Force of the Dividing Cell, Pt. I: The Achromatic Spindle Figure Illustrated by Magnetic Chains of Force," *Proceedings of the Royal Society,* B, Vol. 76, 1905, esp. pp. 555-559.

Some have referred the vital process to the action of spirit, shelving the problem in so far as science is concerned as unreachable and unknowable. But its study constitutes, as Rignano truly says, the real end and aim of all biological study, none of which is without direct relation to it. The conceptions of a few great naturalists have been beacon lights, guiding the course of others, but the fundamental causes are still in darkness. These causes must be sought in the borderland between physical science and biology, and here the help of the physicist is valuable and indispensable, especially if like Rignano, he is able to see clearly in what the fundamental problems of biology consist, and is able also to think synthetically.

The hypothesis contributes to science a basis and guide for further constructive thought and work, and as such cannot fail to fulfil the modest hope of the author that it might be a *travail d'approche* toward true conceptions. And as such it is being gratefully received and carefully considered by many who are still hopeful that these things also will be clearly seen and understood.

Rignano concludes his book by saying that he will be especially grateful to those biologists who will be so good as to send him criticisms or objections, and also to advise him of new facts which can be adduced either for or against his conception.

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